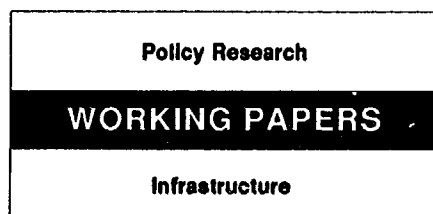


WPS 1066



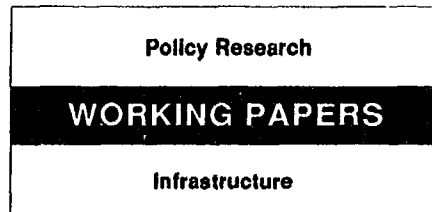
Country Department I
Latin America and the Caribbean
The World Bank
January 1993
WPS 1066

Pollution Control in a Decentralized Economy

Which Level of Government Should Subsidize What in Brazil

**Antonio Estache
and
Kangbin Zheng**

In general, the most effective approach is a state abatement subsidy — kept low — combined with a pollution tax. But when federal or state inspection capabilities are limited, federal monitoring subsidies may be an effective substitute.



WPS 1066

This paper — a product of the Infrastructure Division, Latin America and the Caribbean, Country Department I — is part of a larger effort in the region to design specific reforms that can assist decentralized economies such as Brazil and Venezuela in dealing with unusual sources of policy failures in the area of pollution control. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Antonio Estache, room E10-081, extension 81442 (January 1993, 35 pages).

Subsidies in Brazil essentially serve three purposes:

- Assigned to the right level of government, they could reinforce the effectiveness of pollution taxes in reducing pollution.
- They offer an opportunity for additional combinations of instruments and hence more flexibility in dealing with the specific institutional characteristics of every state.
- They can serve a purely “public relations” effect by showing that the federal government does not always rely on “sticks” but can also provide “carrots.”

Estache and Zheng have four main messages of relevance to the Brazilian economy.

First, carrots will not work without a stick. Subsidies of any type will not work without a coexisting pollution tax.

Second, some carrots are better than others at achieving the government's objectives. In general, a state abatement subsidy is the more effective instrument to combine with a pollution tax. But when federal or state inspection capabilities are limited, monitoring subsidies may be an effective substitute.

Third, increasing abatement subsidy rates can be counterproductive — tending to increase firm investment more than necessary and hence reduce the pollution tax base, while increasing subsidy costs. This can worsen the monitoring and inspection efforts and fiscal revenue.

Finally, it is more effective to keep subsidy rates low if they are to be effective and sustainable and at the same time get the endorsement needed from state and federal fiscal administrations.

The Policy Research Working Paper Series disseminates the findings of work under way in the Bank. An objective of the series is to get these findings out quickly, even if presentations are less than fully polished. The findings, interpretations, and conclusions in these papers do not necessarily represent official Bank policy.

Pollution Control in a Decentralized Economy

Which Level of Government Should Subsidize What in Brazil

by

Antonio Estache
and
Kangbin Zheng

Table of Content

I. Introduction	1
2. The Design of Subsidies for Pollution Control	4
3. The Analytical Framework	5
i. The Firm's Problem	6
ii. The SEPA's Problem	8
iii. The FEPA's Problem	10
4. Policy Simulations	11
i. Who Should Subsidize the Firm: The Federal or State Government	12
ii. Are More Subsidies Necessarily Better?	14
iii. Should the Federal Government Subsidize the Firm or the SEPA?	17
5. Policy Lessons for Brazil	19
Appendix: A Game Model for Taxes, Subsidies and Penalties in Decentralized Pollution Control	21
Bibliography	35

**POLLUTION CONTROL IN A DECENTRALIZED ECONOMY:
WHICH GOVERNMENT LEVEL SHOULD SUBSIDIZE WHAT?**

-- A Case Study of Brazil --

Antonio Estache and Kangbin Zheng

I. Introduction

A recent survey of the use of economic instruments for environmental protection in OECD countries shows that governments frequently rely on subsidies to meet their environmental policy objectives.¹ Increasingly, environmental subsidies are also relied upon in many industrializing countries. In India, Korea, Mexico, Singapore and Taiwan for instance, investments in pollution abatement equipment and facilities can benefit from accelerated depreciation or tax credits.² Also, in Brazil, the Philippines and India, the federal governments try to stimulate investment in abatement by providing subsidized credit to large polluters.

These subsidies are often viewed as a substitute to monitoring. The idea is that if a firm gets paid to control pollution, the government will spend less in monitoring to ensure that the firm complies with the environmental law. In sum, the governments behave as if they were facing a trade-off between: (i) a one time expenditures on sharing the cost of an abatement investment with a firm and (ii) recurrent and capital expenditures on monitoring and enforcing for as long as the firm takes to update its production technology. The more difficult and expensive monitoring is, the more attractive subsidies are likely to be.

A second reason why governments frequently rely on subsidies is more

¹ see Opschoor and Vos (1989), pp74-88 and 116-117.

² see Clarke, S.F. (1991).

political.³ Since for many of the older, more polluting, firms, changes in environmental regulation took place after their investment decision was made, the governments are reluctant to require an immediate compliance with new environmental laws. This aspect of the instrument selection process is actually all the more important in countries such as Brazil, where investment decisions were often distorted by regional and sectoral tax incentives granted by the federal and state governments.

For instance, industrial activity in the metropolitan area of Belo Horizonte, the capital of the State of Minas Gerais in Brazil, is highly concentrated in the municipality of Contagem. For the last 20 years, Contagem has been one of the main industrial employers of the state and a large share of the state tax revenue is credited to production within its borders. Now that the awareness of, and hence accountability for, the cost of pollution has improved in the State, the successive state governments have been torn between the need to address the health risks imposed by industrial pollution and the risks of losing employment and tax revenue as firms that cannot afford to comply in the short run with the new laws disappear.

The policy issues implied by this example are typical and important for a decentralized economy in which the federal government relies on state governments to enforce minimum ambient standards for water and air quality. These policy choices are as follows. Should the state government subsidize the firms? Should it tax the firms' pollution to force them to internalize the costs they have so far imposed on society? Or, should the federal government step in if the state government cannot make up its mind? If the federal government steps in, how should it do it, should it subsidize the firms, should it subsidize monitoring by the state or should it penalize the state for not enforcing the pollution control laws?

These are the issues we address in this paper. They result from the strategic nature of the decision making process in pollution control in Brazil and are hence best analyzed within a game-theoretical framework.

³ There are other types of arguments in the literature. For instance, see Laplante (1990), where a case for subsidy is made to eliminate collusive outcomes in an oligopolistic industry.

This framework updates the one we used in a previous paper to discuss the assignment of pollution based taxes and fines across government levels.⁴ Essentially, the framework focuses on the hierarchized vertical relationship between the Federal Environmental Agency (FEPA), a representative State Environmental Agency (SEPA) and a representative firm. The main difference from the model presented in the previous paper is that various types of subsidies have been explicitly build into the model.⁵

The characteristics of Brazil's "Paper and Printing" industry, a highly polluting sector, are relied upon to illustrate the effects of various combinations of instruments on the objectives of the various agents. In particular, we discuss the substitutability or complementarity between: (i) federal and state abatement subsidies to firms, (ii) federal abatement subsidies to firms and federal monitoring subsidies to states, (iii) states abatement subsidies and pollution taxes, (iv) state pollution taxes and federal fines on states, and (v) the substitutability between monitoring and subsidies.

The remainder of the paper is organized as follows. Section 2 provides an overview of the main types of subsidies for pollution control. Section 3 describes how the main types of subsidies currently under consideration in Brazil have been build into the analytical framework and presents the main theoretical policy results that can be derived from the model. Section 4 discusses the results of simulations of various instrument combinations. Section 5 concludes, summarizing the main policy implications of the analysis. The formal presentation of the model is provided in the Appendix.

⁴ Estache and Zheng (1992)

⁵ In addition, there is a technical difference in that the federal objective function has been modelled as an explicit Lagrangian problem to recognize the importance of the federal budget constraint.

2. The Design of Subsidies for Pollution Control ⁶

Subsidies for pollution control are of two main types: (i) subsidies for emission reduction or (ii) subsidies for technological improvements.⁷ Subsidies for emission reductions are based on the actual quantity of emission reduction. A benchmark emission level is determined for each firm in a given year. For each unit of emission reduction from that benchmark, the firm receives a payment or reward. From an individual firm perspective, this has the same incentive effect as a tax per unit emitted: either the firm gets paid not to pollute or it has to pay to have the "right" to pollute. This equivalence is however misleading. First, the budgetary implications of the two instruments are quite different. Second, an emission based subsidy may be very counterproductive from a full industry perspective and hence for aggregate pollution. It promotes entry into the sector and may maintain financially viable firms that would otherwise have been bankrupt. This sort of subsidy is not commonly considered in developing countries and is then less interesting from a "pragmatic" point of view--in spite of its very impressive coverage in the academic literature.

The second main type of subsidy consists of sharing the costs of investing in pollution control equipment or facilities. It is also the type of subsidy we are assessing in this paper. It is more commonly considered in developing countries as it does not require a recurrent monitoring of pollution sources, a major policy issue in many developing countries. It can take the form of direct grants, tax breaks through credits or accelerated depreciation most commonly or through credit subsidies. The instrument may be a very effective way of ensuring quick reduction in pollution control when the firm was considering to do the investment anyhow

⁶ For more details, see OECD (1989), Baumol and Oates (1988), Fargeix (1992) or Eskeland and Jimenez (1991).

⁷ A third type of subsidy combines characteristics of the two main categories: subsidies to inputs substitution. It will often be linked to technological changes in the production process, and these will limit some of the distortionary incentive effects of it shares with an emission based subsidy.

at some point and is being delayed by financial constraints.

But this type of subsidy is not problem free. For instance, abatement subsidies typically cover the capital component of the cost and not the recurrent costs. Hence, firms may have an incentive to adjust their maintenance effort to the frequency with which they can be eligible for abatement subsidies. Another practical problem encountered is the excessive specificity on the subsidized technology. Often an EPA's tendency is to focus on specific equipment types such as treatment stations, but in practice, this may not be the most efficient method to cut pollution.⁸

The final type of issue raised by technology based subsidies is the most general and is the focus of this paper. When a firm has no intention to invest in pollution control unless it is required to, the subsidy is unlikely to be effective unless it covers the full cost of the investment. This probably explains why, in Brazil, instruments relied upon in the past by the National Development Bank that are partial in nature, such as interest rate subsidies or tax credits that reduce the tax liability by less than the abatement cost, performed so poorly. For a less-than-full subsidy to be effective, additional pollution control has to be relied upon to make sure that the overall incentive structure created by the design of environmental policies are consistent with its objectives.

3. The Analytical Framework

This section describes the model relied upon to assess the importance of strategic behavior for the decision to subsidize pollution abatement in Brazil. It reproduces the main interactions between the three agents involved in pollution control: the federal environmental protection agency (FEPA), the state environmental protection agency (SEPA) and the firm. The FEPA set minimum ambient standards. The SEPA is supposed to enforce them and has the option to improve upon them. There is no special federal budget allocation to the states to finance their enforcement role. The firm is expected to comply.

⁸ see Fargeix (1992), p12 on this and Baumol and Oates (1988), footnote 6, p213.

The model reproduces the short run vertical relationship between the FEPA, a representative SEPA and a representative firm. The SEPA maximizes its tax revenue, net of subsidies. The firm maximizes its after tax profits. The FEPA is a Stackelberg leader and maximizes the social welfare of the economy under budget constraint. The FEPA knows the SEPA and firm's objectives but the SEPA and the firm may not be perfectly aware of the FEPA's intention. They select their optimal behavior as a reaction to the FEPA's strategy selection. This behavior is also build into the FEPA's optimizing strategy and hence used to influence the SEPA's policy choices and hence firm's behavior as the SEPA is a Stackelberg leader in its relationship with the firm.

The specific mathematical formulation of this sequence of maximizing behavior is provided in the appendix. The remainder of this section provides a brief overview of the economics underlying the behavior of each agent and of the theoretical policy implications of various forms of government intervention.

i. The Firm's Problem

The firm has a fixed capital stock it can use to produce or to abate pollution. Its production technology is associated with a pollution function which depends on the output level and on the abatement intensity and technology. The costs to the firm of the investment in abatement can be reduced by a SEPA or FEPA decision to grant subsidies. Unless these subsidies cover 100% of the investment cost, however, the firm's output, and hence profits, will be reduced when it complies with the environmental law. The firm's profits can also be affected by a pollution tax and the sales tax. The pollution tax is based on emission and can only be collected if the SEPA actually monitors the firm. From the firm's point of view, this means that only the effective pollution tax matters. This effective tax rate is the nominal tax rate weighted by the firm's probability of being monitored. If the SEPA never monitors the firm, the effective tax rate is zero.

The firm has then to decide how to allocate its fixed amount of capital between production and pollution control to maximize its expected profits. If the effective tax rate is zero and the subsidy, whether Federal

or State, is less than 100%, the firm has no short run incentive to invest in pollution control as it would lower output and hence sales revenue. As soon as the effective pollution tax becomes positive, the incentive to invest in abatement increases as it can result in reductions in the pollution tax liability. Subsidies enhance this incentive.

The firm chooses its investment by comparing the marginal cost (MC) of abating pollution with the marginal benefit (MB) of doing so. The marginal cost is reflected in the loss of after-tax profits due to the diversion of resources from production to pollution control. It is determined by the sales tax and the investment in abatement. The MB is the savings in pollution tax liability achieved through the investment in abatement. This saving depends on the efficiency of the abatement technology selected by the firm but also on the subsidy rates for investment in abatement offered by the FEPA and the SEPA. Subsidies contribute to the determination of the marginal benefit.

The solution to the firm's problem leads to these theoretical results:

Implication 1: Technology-based subsidies will increase the marginal benefit of abatement to a firm as well as its profits. Hence these subsidies will enhance the incentive to invest in pollution control but to be effective, they have to be combined with a pollution tax instrument.

Implication 2: The inclusion of subsidies in the menu of pollution control instruments allows a reduction in the minimum effective pollution tax rate required to avoid that the firm completely ignores its environmental responsibilities. Hence the SEPA can cut monitoring or the tax rate. Alternatively, at any given level of monitoring and tax rate, subsidies can be used to improve the impact of the pollution tax.

Implication 3: The dirtier the industry and the lower the effectiveness of the abatement device, the more effective monitoring is as compared to subsidies in altering the firm's behavior.

Implication 4: From the firm's perspective, federal subsidies and state subsidies are equally good. They result in a lower share of the firm's total capital required to fully abate pollution. Hence subsidies result in lower output and profit costs for a given level of reduction in pollution as compared to a policy relying exclusively on a pollution tax.

The first conclusion qualifies the standard tax-subsidy equivalence result usually demonstrated in the literature for emission based subsidies rather than for technology based subsidies. At very low levels of effective tax rates, taxes and subsidies are actually complements rather than substitutes. It is only at higher tax rate levels that they become substitutes from the firm's perspective.⁹

From a practical point of view, it is a crucial result as in many of the countries considering subsidies to polluters for investment in abatement, there is no pollution tax. The failure to combine the introduction of subsidies, whether from SEPA or FEPA, with the adoption of pollution taxes, at any government level, is unlikely to prove successful in terms of pollution reduction unless the firm already had the intention of investing in abatement. In fact, to be conservative, the model suggests that it is probably wiser to start a reform in pollution management in Brazil with the introduction of the tax to establish the credibility of reform intentions. Once the tax is being enforced, it makes sense to consider subsidies to cut the effective tax rate.

ii. The SEPA's problem

The state government wants to maximize the sum of sales and pollution tax revenue net of the costs of: (i) subsidies to firms, (ii) monitoring the firms and (iii) fines due to the federal government if the FEPA finds out that the SEPA has not monitored the firm. The monitoring cost is assumed to be fixed. The Federal government may be willing to share the costs of monitoring the firm by providing a subsidy for resources spent on monitoring by the states. It represents essentially the cost of sending people to the polluting factory and the costs of the laboratory analysis of the samples collected. The tax and subsidy rates are imposed on the SEPA. Or equivalently, they have to be set an identical rate for all sectors for administrative or political reasons and can hence not be selected as a

⁹ The case for tax-cum-subsidy solution for pollution control has already been argued for in the literature. See for instance, Yohe and MacAvoy (1987) and for a survey of the literature on tax-cum-subsidies Kohn(1990)

policy instrument by the authorities. In the very short run, the only decision variable available to the SEPA is its monitoring frequency and the decision on whether or not to subsidize the firm at any given level of subsidy rate. In the medium run, it can lobby for changes in pollution subsidy and tax rates.

In the short run, the SEPA will determine its optimal monitoring choice by comparing the aggregate marginal monitoring costs and benefits. Its *total marginal monitoring cost* depends on (i) the monitoring cost; (ii) the subsidy cost; (iii) the cost due to the reduction in the sales tax base and (iv) the cost due to the reduction in the pollution tax base. Its *total marginal monitoring benefit* is the sum of (i) the federal penalty avoided and (ii) the additional pollution tax collected as a result of a harsher monitoring.

The SEPA's monitoring efforts could then be increased by cutting marginal costs or increasing marginal benefits. Two types of subsidies could be considered to try to reduce total marginal cost and hence increase the monitoring effort. The first is a subsidy to monitoring, the second is a reduction in the subsidy to the firm by either the SEPA or the FEPA. Marginal benefits would improve with an increase in pollution tax rates or federal penalties on SEPAs. The policy implication of these observations can be summarized as follows.

Implication 5: As federal subsidies for monitoring increase, the SEPA allocates more resources to controlling pollution. The higher the pollution tax rate, the monitoring cost and the potential federal penalty on the SEPA, the higher the effect of the federal subsidy to the SEPA on its monitoring efforts. The lower the federal and state subsidies to the firm the more the monitoring subsidy will stimulate SEPA's monitoring effort.

In addition to the obvious conclusion that a higher federal penalty rate on the SEPA will increase the effectiveness of monitoring subsidies, the more practical implications of the results are somewhat unexpected. First, the federal government should not subsidize both the firm and the SEPA as the first instrument dampens the impact of the second one. Next, if the SEPA is not devoted enough to its monitoring requirements, it can

either increase the pollution tax rate on the firms (the stick approach) or subsidize its monitoring efforts (the carrot approach).

iii. The FEPA's problem

The federal government is growth oriented and thus cares about the output levels. But its electorate cares about the environment so the federal government also wants to keep pollution under control. These two partial objectives are reflected in the federal government's overall objective function. FEPA's policies are designed to maximize it under budget constraint. It can be viewed as a social welfare function.

In principle, for any given sector, FEPA's main decision variables are: (i) its inspection effort to check how well the states do what they are supposed to do, (ii) the penalty level it should threaten the states with, and (iii) the subsidy rates to both the states and the firms. In practice, the penalty levels and subsidy rates are often set for all sectors and can hence not be used as policy variables in dealing with any specific sector. In sum, the only actual policy variable the federal government has is SEPA's inspection rate and the decision on whether or not to subsidize the firm or the SEPA at any given subsidy rate level.

The main result of this maximization problem is that the FEPA should pick its inspection rate to equate the marginal benefit and the marginal cost of pollution of its monitoring policy. The main impact of federal subsidies to the states or to the firm are obvious: they will increase the marginal cost of monitoring and hence reduce the incentive to do so. This has the following implication:

Implication 6: *To achieve a given level of SEPA inspection rate and for a given pollution tax rate, the introduction of federal subsidies, to the firms or to the states, in the menu of instruments for pollution control requires a compensating increase in either the federal inspection effort or in the federal penalty level imposed on the SEPAs for non-compliance with their mandate to control pollution.*

The model also illustrates the importance of the budget constraint for FEPA's choice of optimal monitoring effort. This choice is drastically

complicated by the introduction of subsidies in the menu of instruments for pollution control policies. In general, however, subsidies make it more likely that the budget constraint will be binding and may hence require adjustments in the federal fine levels to alleviate the impact of the constraint on the optimal monitoring choice. The impact of the changes in the shadow value of a federal budgetary improvement will thus depend on the existing level of fines, monitoring and inspection costs and on the impact of SEPA's monitoring on the firm's behavior. Its sign is uncertain.

The mathematical form of the other results of these optimization problems does not directly provide much policy insights. Indeed, its complexity impedes the derivation of clear policy lessons for the optimal form of FEPA's intervention. We therefore resort to simulations to draw some additional conclusions from the analytical framework. The results of these simulations and their lessons are discussed in the next section.

4. Policy Simulations

This section presents numerical simulations aiming at answering three main questions: (i) Should the FEPA or should the SEPA subsidize firms? (ii) Are More subsidies necessarily better?, and (iii) Should the FEPA subsidize abatement by the firms or monitoring by the states? These three questions are at the core of the overall design of pollution control policies in a decentralized economy such as Brazil.

The simulations are based on a representative firm of the "Paper and Printing" industry of Brazil.¹⁰ The interest in this industry stems from three main factors. First, this a typical "dirty" industry and hence one on which environmental protection agencies frequently tend to focus on. This implies that recurrent resources to be allocated to monitoring that sector are likely to be higher than average. Hence, the potential permanent pollution reduction benefits of a one time federal subsidies to monitoring that sector deserve a more detailed assessment. Second, for states in which the industry is large enough in terms of output, it is a clear candidate to

¹⁰ Details on the estimates of the production functions and other data related issues are provided in the Appendix to Estache and Zheng (1992).

be eligible for federal or states subsidies. Finally, the potential revenue effect of a pollution tax on emissions from this sector is high enough to avoid having to base policy choices on extremely binding budget constraints.

i. Who Should Subsidize the Firm: The Federal or State Governments?

The National Development Bank of Brazil (BNDES) has a program of subsidized credit available to highly polluting industries in a few states. Besides the weaknesses of this program due to the limited use of pollution taxes in Brazil, there is another characteristic of this program that deserves some attention. Why should it be a federal subsidy program rather than a state subsidy program?

Table 1 below reports the result of simulations comparing a federal and a state 25% subsidy to the firm for the purchase of abatement equipment. The benchmark is provided by the first column of the table which reflects a case in which there are no subsidies at all. The table shows the impact on the main variables when the pollution tax rate is set at its optimal value and there are no subsidies for SEPA monitoring. The results reported here are robust. They hold for suboptimal tax rates and for different levels of federal penalty levels on the SEPA for non-compliance.

The last line of the Table provides a summary indicator that reflects the choice of the social welfare function selected. In particular, it assumes a specific level a federal disutility with regard to pollution and a specific shadow price for the budgetary constraint.¹¹ The first major

¹¹ The value of the marginal disutility of pollution here is 1, but the federal inspection effort and the hence above results are not significantly altered for value of the marginal disutility of pollution of up to twice the value selected here. After that, however, an increase in disutility will result in an increase in federal monitoring of the SEPA. The value for the shadow price of the budget constraint is also 1. The sign of the effect of a change in this value is uncertain. It depends on its financial implications of a change in the FEPA inspection efforts. If the combination of federal instruments result in a self-sustained overall policy, then the FEPA could actually earn a positive net revenue while reducing pollution. In general, however, in the more realistic cases, FEPA's policies will lose money and hence require budgetary allocations in is the case for the results reported in Table 1.

conclusion is that any one of the three policy options considered will lead to improvements over a situation in which the government does not intervene to force the firms to internalize the costs of pollution.

The second main lesson stems from the ranking of these policy options. The best policy is to combine a pollution tax with a state subsidy to the firms rather than with a federal subsidy to firms. This is explained by the incentive effect of the budgetary implications of the subsidy assignment. As the costs of subsidies increase and their effect on pollution reduce the pollution tax base, the states have an incentive to increase monitoring to offset the revenue loss that stems from these two sources. But after a threshold monitoring level, further increases in monitoring also lead to lower revenue as firms tend to comply more.

**Table 1: Effect on the Agents' Behavior of
a Combination of a Pollution Tax with Various Subsidies**

(expressed as % of value of a variable
without government intervention unless otherwise specified)

	No Subsidy	25% Federal Subsidy to firm	25% State Subsidy to firm
Social Welfare Level	103.6%	102.5%	105.7%
Firm's Optimal Behavior			
Abatement Investment as % of Initial Capital	13.8%	11.0%	13.8%
Output Level	95.2%	96.8%	95.2%
Pollution Level	58.7%	59.3%	49.5%
Profit Level	82.7%	88.3%	86.6%
SEPA's Optimal Behavior			
Minimum Monitoring Rate Required for non-0 pollution abatement	3.4%	4.1%	4.1%
Optimal Monitoring Rate	43.1%	42.7%	52.4%
Nominal Pollution Tax Rate	2.7%	1.8%	1.8%
% cut in VAT Revenue	4.8%	3.2%	4.8%
Pollution Tax Revenue as % of VAT Revenue	48.8%	33.0%	33.7%
Net Revenue	142.0%	127.9%	112.2%
FEPA's Optimal Behavior			
Optimal Inspection Rate	0%	0%	0%

The federal subsidy to the firms is the less effective of the three options even if it is likely to be preferred by states as they are significantly better off than when they have to finance the subsidy. The revenue loss that results from lower pollution levels is not strong enough to stimulate the states to monitor more. In fact, since pollution tax revenue from the effective pollution tax rate follows a Laffer curve--i.e. they peak at the optimal monitoring rate and then starts declining--, and since federal subsidies results in lower pollution without the subsidy income effect for the state, the states have an incentive to monitor less to collect more tax revenue. We will discuss this explanation in more details in a later section.¹²

Implication 5: For a given subsidy rate, a state abatement subsidy reinforces the effectiveness of the pollution tax while a federal abatement subsidy may reduce it.

ii. Are More Subsidies Necessarily Better?

The previous section established the superiority of the state subsidy policy option over a policy that would rely exclusively on a pollution tax. It did not, however, establish this result for all levels of subsidies. Table 2 illustrates the effect of various levels of state subsidies on the behavior of the three agents. They were computed under the assumption that the pollution tax rate was set at its optimal level. But the main policy conclusions would not be altered if rates were set at sub-optimal levels.

These simulations illustrate the limitations of subsidies stemming from Implication 4. It was already clear from the theoretical analysis that a full subsidy to the firm, whether from the state or from the federal

¹² The optimal federal inspection rate is 0 because the incentive effect of the pollution tax is sufficient to convince the SEPA to monitor this dirty industry. As shown in the earlier paper, optimal federal inspection rates are higher for cleaner industry as the potential revenue effect of a state pollution tax is compelling for the states and require a federal involvement.

government, would be self defeating.¹³ The 90% subsidy simulation shows that states subsidies are more effective than federal subsidies. But it also shows, that it could be a revenue disaster for the states. This is confirmed by the 50% subsidy simulation.

Table 2: Importance of the Subsidy Level for its Effectiveness
(expressed as % of value of a variable
without government intervention unless otherwise specified)

	<i>State Subsidy Level</i>			<i>Federal Subsidy Level</i>		
	25%	50%	90%	25%	50%	90%
Social Welfare Level	105.7%	110.5%	121.1%	102.5%	100.7%	100%
Firm's Optimal Behavior						
Abatement Investment as % of Initial Capital	13.8%	15.9%	4.6%	11.0%	7.6%	0.0%
Output Level	95.2%	93.7%	99.3%	96.8%	98.4%	100%
Pollution Level	49.5%	20.4%	3.8%	59.7%	61.8%	100%
SEPA's Optimal Behavior						
Minimum Monitoring Rate Required for Abatement to Start	4.1%	5.5%	20.3%	4.1%	5.5%	20.3%
Optimal Monitoring Rate	52.4%	80.7%	100%	42.7%	41.6%	8.7%
Nominal Pollution Tax Rate	1.8%	1.0%	0.1%	1.8%	1.0%	0.0%
% cut in VAT Revenue	4.8%	6.3%	0.7%	3.2%	1.6%	0.0%
Pollution Tax Revenue as % of VAT Revenue	33.7%	11.6%	0.2%	33.0%	18.2%	0.0%
Net Revenue	112.2%	52.0%	-33.8%	127.9%	114.6%	100%

The 90% subsidy simulations also provide some additional insights. They show that when the firms are asked to contribute even, very modestly,

¹³ The mod. can actually not predict the firm optimal behavior under full subsidization because there is a time inconsistency problem, not handled in its design. In practice, if the FEPA notices that the firms do not take advantage of the subsidy offer, it knows it will it has to improve monitoring. The analysis of this better use of information requires a dynamic framework for mechanism design with incentive compatibility.

say 10%, to the cost of abatement, they will only do so when the state has an incentive to monitor the firms. When the federal government subsidizes the firms, its optimal policy is not to monitor the SEPA. This in turn will reduce the incentive of SEPAs to inspect the firms. Since firms need to face a monitoring rate of at least 20.3% to start abating and since the revenue maximizing monitoring rate is only 8.7% when the FEPA does not check on the SEPA, the firms have no incentive to take abate at all.

While the federal "social welfare function" indicates that the society is better off with an increase in the state subsidy rate and worse off with an increase in federal subsidy rates, an analysis of the individual results raises some concerns about their immediate policy value. Most importantly, it shows that the revenue implication of too high a state subsidy are unbearable. The assignment of pollution control responsibilities would end up reducing the state's net revenue quite significantly. This in turn would mean that improvements in pollution control would have to be achieved by crowding out other expenditures at the state level or by increasing deficits.

It is thus politically unrealistic to expect any form of state endorsement for full subsidies. The states behavior would end up being driven by an attempt to minimize losses from pollution control activities rather than by an attempt to maximize revenue. A proposal for this sort of subsidy is unlikely to receive support from decentralized governments.

While states will tend to prefer a federal subsidy to a state subsidy, they are also likely to have some views on the federal subsidy level. In general, they will prefer to have low subsidy rates as the higher the subsidy, the lower the pollution level and hence the lower their pollution tax base.

Implication 6: To achieve their socially desirable impact and to ensure their political support on the part of the states, subsidies rate should be set at levels that do not end up reducing states net revenue.

c. Should the Federal Government Subsidize the Firm or the SEPA?

Even if a state subsidy is a more desirable policy than a federal subsidy from an economic point of view, non-economic reasons may lead the federal government to take the leadership and assume the initial costs of subsidies. In that case, it seems reasonable to discuss the allocation of federal resources. Should the Federal government subsidize abatement by the firms or should it subsidize monitoring by the states?

The simulations results reported in Table 3 reflect a somewhat different institutional setup from the one relied upon so far. The pollution tax rate has been set arbitrarily at 1%. This is not necessarily optimal. It represents, however, a realistic situation as it is unlikely that any government will be able to tax all sectors optimally. While the federal government was not relying on any penalty to increase the incentive of SEPAs to monitor, we assume here that the federal government relies on that instrument as well and imposes very high penalty--about 30% of the original sales tax revenue from the polluting sector--when it finds out that a SEPA has not been inspecting polluters. The subsidy rate whether federal or state and whether to the firm or to the SEPA is 25%.

At these subsidies levels, a federal subsidy to the SEPA leads to a lower social welfare than a state subsidy to the firm. It is however, more effective than a federal subsidy to the firm. Strictly in terms of its effect on pollution reduction, it is however the less effective of the three forms of policy intervention even it leads to a perfect monitoring by the states thanks to the reduction in the marginal cost of monitoring. From the states point of view it is probably the most attractive solution as it leads to its highest net revenue level. To increase its effectiveness in terms of pollution reduction, it would have to be combined with an increase in the pollution tax rate as it is a crucial instrument to change the behavior of the firm and improve its compliance.

Subsidies to the firm lead to significantly lower pollution levels but require, for this low tax rate level, an active inspection effort by the federal government. The state revenue payoff of SEPAs' monitoring efforts are too low as compared to the full cost of monitoring because direct subsidies to the firm tend to reduce the pollution tax base more directly

and hence the tax revenue. This reduces the marginal benefits of monitoring from the firm. In sum, the state prefer monitoring subsidies because it tends to increase the average effective tax rate and revenue as compared to a subsidy to the firm.

Table 3: Comparing the Effectiveness of Federal to firms and to SEPAs
(expressed as % of value of a variable
without government intervention unless otherwise specified)

	<i>Subsidy to firm by SEPA by FEPA</i>		<i>Subsidy to SEPA</i>
Social Welfare Level	105.7%	102.5%	103.7%
Firm's Optimal Behavior			
Abatement Investment as % of Initial Capital	14.4%	12.2%	11.9%
Output Level	94.8%	96.2%	96.4%
Pollution Level	47.1%	55.4%	64.4%
SEPA's Optimal Behavior			
Minimum Monitoring Rate Needed for abatement to start	7.3%	7.3%	8.9%
Optimal Monitoring Rate	97.8%	83.6%	100.0%
Nominal Pollution Tax Rate	1.0%	1.0%	1.0%
% cut in VAT Revenue	5.2%	3.8%	3.6%
Pollution Tax Revenue as % of VAT Revenue	33.4%	33.6%	46.7%
Net Revenue	113.0%	128.9%	142.9%
FEPA's Optimal Behavior			
Optimal Inspection Rate	5.0%	15.0%	0.0%

From the FEPA point of view, the ranking of these two policies depends on the importance of the federal budget constraint. Subsidizing a SEPA is generally likely to be significantly cheaper than subsidizing the firm, at least in the short run. This is because firms' abatement costs tend to be higher than states monitoring costs but also because an abatement subsidy will require an active federal inspection effort which the monitoring

subsidy does not require. It is thus likely that, when the budget constraint is binding, the FEPA will generally tend to prefer a subsidy to the SEPA over a subsidy to the firm. This explains why in Brazil, as in many developing countries, a monitoring subsidy may be more desirable than an abatement subsidy.

From the FEPA perspective, the monitoring subsidy has an additional attraction. It can be a substitute to expenditure to be allocated to inspecting the states. In the very short run, as the federal government faces constraints imposed the shortages of qualified staff, monitoring subsidies may prove to be a very attractive solution to improve the overall effectiveness of pollution control in Brazil.

Implication 7: When both the federal and the state governments pollution control efforts are, at least partially, determined by budgetary considerations, monitoring subsidies are more desirable than abatement subsidies.

5. Policy Lessons for Brazil

This section attempts to narrow down the desirable path for federal and state subsidy policies in general. The emphasis is on the practical lessons of the paper. In particular, it highlights the role that subsidies can have in increasing the variety of combinations of instruments that can be relied upon to implement pollution control objectives without omitting growth targets.

Subsidies in Brazil would essentially serve three purposes: (i) if assigned to the right government level, they could reinforce the effectiveness of pollution taxes in terms of pollution reduction; (ii) they offer an opportunity for additional combinations of instruments and hence provide greater flexibility in dealing with the specific institutional characteristics of every state; (iii) they can serve a purely "public relations" effect by showing that the federal government does not always relies on "sticks" but can also provide "carrots".

From a purely economic perspective, the paper has three main messages of direct relevance to the Brazilian situation. First, carrots will not

work without a stick. In other words, subsidies--of any type-- will not work without a coexisting pollution tax. Second, some "carrots" are better than others at achieving the government's objectives. In general, a state abatement subsidy is the more effective instrument to be combined with a pollution tax. However, when federal or state inspection capabilities are limited, monitoring subsidies can provide an effective substitute. Third, increases in abatement subsidy rates can be counterproductive. They tend to increase firm investment and hence reduce the pollution tax base while increasing subsidy costs. This can lead to a worsening of the monitoring and inspection efforts by both the FEPA and the SEPA but as importantly of their fiscal revenue. In sum, the lesson is that it is more effective to keep the subsidy rates low if they are to be both effective, sustainable, and enjoy the necessary endorsement from the state or federal fiscal administrations.

Appendix: A Game Model for Taxes, Subsidies and Penalties in Decentralized Pollution Control

This appendix establishes a game-theoretical framework which underlies the interdependence and interaction between behaviors of different levels of economic agents. Essentially, we define the problem of assigning and designing policy instruments for decentralized pollution control as a hierarchical Stackelberg game played between three levels of decision makers: a representative firm, a representative SEPA and the FEPA.

The Firm's Problem

To simplify our presentation without losing much policy insight, we concentrate on a representative firm in a specific sector of a developing economy, in which environmental management is decentralized in the sense that any economic agent is able to decide what to do and how to proceed by weighing its own gains against its cost when environmental responsibility is concerned. As a by-product of its production, the firm emits some toxic release into the environment. Since this emission pollutes and is subject to potential pollution taxes and penalties, the firm may find it in its interest to purchase certain abatement facilities. With subsidies from either the state authority (the SEPA) or the federal authority (the FEPA), the firm knows that its investment for pollution control, I , can be presented as

$$I = (1 - s_r - s_f) C, \quad s_r, s_f \geq 0, \quad 0 \leq s_r + s_f < 1 \quad (1)$$

where s_r and s_f are the state and federal subsidization rates, respectively, and C is the market cost of the pollution abatement device. For any given abatement device cost, the higher the subsidization rate from either the SEPA or the FEPA, the smaller the firm's contribution portion. On the other hand, for any given set of subsidization rates, the more the firm invests for pollution control, the larger the abatement facility. Namely, (1) can be rewritten as

$$C = \frac{1}{1 - s_r - s_f} I \quad (2)$$

where $1/(1-s_r-s_f)$ works as a subsidization multiplier for the firm's environmental protection investment. In the short-run, the firm holds a fixed total capital stock K . The firm's production function, assumed to be quadratic in its productive capital $K - I$, can be written as

$$Y = \alpha (K - I)^2 + \beta (K - I) + \gamma, \quad \alpha < 0, \quad \beta > 0 \quad (3)$$

which can be regarded as a second order Taylor approximation to any twice differentiable production technology in the concerned neighborhood. Here α , β and γ are parameters reflecting the firm's production technological status. Generally, we require that α be negative to ensure the concavity of the production function and that $\beta > -2\alpha K$ to ensure a positive marginal product of capital when $I = 0$.

Since a part of the capital stock is shifted away for environmental protection, investment for pollution control reduces the firm's output level

$$\frac{dY}{dI} = - [2\alpha(K - I) + \beta] \leq 0 \quad (4)$$

Pollution intensity in the environment, denoted by P , is positively correlated with the output level but negatively correlated with the size of the pollution control facility C . Hence, we can write out a general pollution function as

$$P = p(Y, C) \quad p_1 > 0, \quad p_2 < 0 \quad (5)$$

where p_1 and p_2 are partial derivatives of P with respect to Y and C . Due to the measurement and identification difficulty, the pollution intensity is often linked to some pollution generating factors. Taking the productive capital as our measurement proxy, we can, for presentation simplicity, linearize the pollution function as

$$P = \psi (K - I) - \omega C \geq 0, \quad \psi \geq 0, \quad \omega \geq 0 \quad (6)$$

where ψ is the capital pollution rate in terms of, e.g., pounds of pollution release generated by a dollar value of capital, and ω is the abatement rate of the firm's pollution control facility in terms of, e.g., pounds of pollution release cleared by a dollar value of C . Obviously, the firm's investment for pollution control reduces the pollution intensity

$$\frac{dP}{dI} = -\psi - \omega \frac{dC}{dI} = -\psi - \frac{\omega}{1 - s_r - s_f} < 0 \quad (7)$$

Clearly, the larger the subsidization multiplier, the larger the marginal reduction rate for pollution control investment. In other words, government subsidies enhance the abatement effectiveness of the firm's pollution control efforts. This can be seen from

$$\frac{\partial}{\partial (s_r + s_f)} \left(\frac{dP}{dI} \right) = - \frac{\omega}{(1 - s_r - s_f)^2} < 0 \quad (8)$$

The firm has two tax obligations: a VAT at rate t_y and a pollution tax at a nominal rate t_p but realized only when the SEPA monitors. For given K and tax policy, the firm maximizes its expected profit given as the following profit function

$$\Pi(I; K) = (1 - t_y) Y - rK - \theta t_p P \quad (9)$$

by selecting its optimal pollution control investment I . Here θ in $[0, 1]$ is the SEPA's monitoring frequency and rK is the firm's fixed capital cost. The change of the firm's profit due to changes in its investment for pollution control can be obtained by using the chain rule

$$\begin{aligned} \frac{d\Pi}{dI} &= (1 - t_y) \frac{dY}{dI} - \theta t_p \frac{dP}{dI} \\ &= - (1 - t_y) [2\alpha (K - I) + \beta] + \theta t_p \left[\psi + \frac{\omega}{1 - s_r - s_f} \right] \end{aligned} \quad (10)$$

The second order condition for the firm's profit maximization problem

$$\frac{d^2\Pi}{dI^2} = 2\alpha (1 - t_y) < 0 \quad (11)$$

is satisfied for all possible choice of I . The first order condition is then

$$(1 - t_y) [\beta + 2\alpha (K - I)] = \left[\psi + \frac{\omega}{1 - s_r - s_f} \right] \theta t_p \quad (12)$$

The firm will invest for environmental protection until the marginal cost in terms of sales loss equals the marginal benefit in terms of the

pollution tax avoided. From (12), we see that the bigger the subsidization multiplier, the higher the marginal benefit for pollution control and the more incentive the firm will have to allocate funds for environmental protection. For any given policy mix $(t_y, t_p, \theta, s_r, s_f)$, the firm's optimal investment for pollution control is, since $0 \leq I \leq K$,

$$I(t_y, t_p, \theta, s_r, s_f) = \max \left\{ 0, \min \left\{ K, K + \frac{\beta}{2\alpha} - \frac{\theta t_p}{2\alpha(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) \right\} \right\} \quad (13)$$

which can be regarded as the firm's best reaction function to the FEPA and SEPA's tax policies. The minimum effective pollution rate tax to make the firm not completely ignore its environmental responsibility is

$$\theta t_p > \frac{(1-t_y)(\beta + 2\alpha K)}{\psi + \frac{\omega}{1-s_r-s_f}} \quad (14)$$

So we see that a rise in either the state or federal subsidy rate will require a lower effective pollution tax rate to make the firm aware its environmental responsibility. The pollution control investment ceiling, at which pollution generated by the firm is completely eliminated, can be expressed as

$$0 \leq \frac{I}{K} \leq \frac{\psi}{\psi + \frac{\omega}{1-s_r-s_f}} \leq 1 \quad (15)$$

which is completely determined by the firm's pollution and abatement intensities, and the government decision on subsidizing pollution control. Apparently, a higher subsidy rate lowers the pollution control investment ceiling.

To derive meaningful and interesting policy implications, we assume an interior solution for I in $(0, K)$. The consequent capital stock the firm will allocate for production is then

$$K - I(t_y, t_p, \theta, s_r, s_f) = -\frac{\beta}{2\alpha} + \frac{\theta t_p}{2\alpha(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) \quad (16)$$

which has a negative correlation with the effective pollution tax rate but a positive correlation with the subsidy rates. The consequent pollution release can be also written as a best reaction function to the environmental policy mix,

$$P(t_y, t_p, \theta, s_r, s_f) = -\frac{\beta}{2\alpha}\psi - \frac{\omega}{1-s_r-s_f}\left(\frac{\beta}{2\alpha} + K\right) + \frac{\theta t_p}{2\alpha(1-t_y)}\left(\psi + \frac{\omega}{1-s_r-s_f}\right)^2 \quad (17)$$

If the SEPA has a maximum pollution tolerance level, denoted by P_{\max} , and a positive expected (planned) monitoring rate, $E(\theta) > 0$, the SEPA will set a pollution tax rate at least as high as the following "minimum required pollution tax rate":

$$t_p^r = \frac{1-t_y}{E(\theta)}\left(\psi + \frac{\omega}{1-s_r-s_f}\right)^{-2}\left[\frac{\omega(\beta + 2\alpha K)}{1-s_r-s_f} + \beta\psi + 2\alpha P_{\max}\right] \quad (18)$$

The firm's reaction to changes of the SEPA's monitoring can be summarized as: an increase in the SEPA's monitoring rate will (a) stimulate the firm to invest more for pollution control, (b) thus reduce the firm's output level, and (c) cut down the pollution release in the environment. These are verified by examining the following equations,

$$\frac{\partial I}{\partial \theta} = -\frac{t_p}{2\alpha(1-t_y)}\left(\psi + \frac{\omega}{1-s_r-s_f}\right) > 0 \quad (19)$$

$$\frac{\partial Y}{\partial \theta} = \frac{dY}{dI} \frac{\partial I}{\partial \theta} = \frac{\theta}{2\alpha}\left[\frac{t_p}{(1-t_y)}\left(\psi + \frac{\omega}{1-s_r-s_f}\right)\right]^2 < 0 \quad (20)$$

$$\frac{\partial P}{\partial \theta} = \frac{t_p \left(\psi + \frac{\omega}{1 - s_r - s_f} \right)^2}{2\alpha(1 - t_y)} < 0 \quad (21)$$

It is worthwhile to note that there exist equal pollution tax and monitoring elasticities on the investment for environmental protection, pollution intensity and output level,

$$\left\{ \begin{array}{l} \frac{t_p}{I} \frac{\partial I}{\partial t_p} - \frac{\theta}{I} \frac{\partial I}{\partial \theta} = 0 \\ \frac{t_p}{P} \frac{\partial P}{\partial t_p} - \frac{\theta}{P} \frac{\partial P}{\partial \theta} = 0 \\ \frac{t_p}{Y} \frac{\partial Y}{\partial t_p} - \frac{\theta}{Y} \frac{\partial Y}{\partial \theta} = \frac{I}{Y} \frac{dY}{dI} \left(\frac{t_p}{I} \frac{\partial I}{\partial t_p} - \frac{\theta}{I} \frac{\partial I}{\partial \theta} \right) = 0 \end{array} \right. \quad (22)$$

which means that the same percentage change in the nominal pollution tax and in the monitoring rate will have identical policy impact on the firm's behavior.

The firm will increase its investment for pollution control when the subsidy rate increases. Subsidies from the state and from the federal are equally good.

$$\frac{\partial I}{\partial s_r} = \frac{\partial I}{\partial s_f} = - \frac{\omega \theta t_p}{2\alpha(1 - t_y)(1 - s_r - s_f)^2} > 0 \quad (23)$$

The size of the firm's pollution control facility will be enlarged with a larger subsidy rate, since the firm has more incentive to invest and the more it invests, the more subsidies it will get.

$$\frac{\partial C}{\partial s_r} = \frac{\partial C}{\partial s_f} = \frac{I}{(1 - s_r - s_f)^2} + \frac{1}{1 - s_r - s_f} \frac{\partial I}{\partial s_r} > 0 \quad (24)$$

However, increase of subsidization will reduce the output level,

$$\frac{\partial Y}{\partial s_r} = \frac{\partial Y}{\partial s_f} = \frac{dY}{dI} \frac{\partial I}{\partial s_r} = -[2\alpha(K-I) + \beta] \frac{\partial I}{\partial s_r} < 0 \quad (25)$$

since subsidies attract the firm to invest more for pollution control. S intuitively, more subsidies reduce the pollution release in the environment.

$$\frac{\partial P}{\partial s_r} = \frac{\partial P}{\partial s_f} = \frac{dP}{dC} \frac{\partial C}{\partial s_r} = -[\psi(1 - s_r - s_f) + \omega] \frac{\partial C}{\partial s_r} < 0 \quad (26)$$

Meanwhile, subsidies enhance the effectiveness of the SEPA's monitoring policy

$$\begin{cases} \frac{\partial}{\partial s_r} \left(\frac{\partial I}{\partial \theta} \right) = \frac{\partial}{\partial s_f} \left(\frac{\partial I}{\partial \theta} \right) = - \frac{\omega t_p}{2\alpha(1 - t_y)(1 - s_r - s_f)^2} > 0 \\ \frac{\partial}{\partial s_r} \left(\frac{\partial P}{\partial \theta} \right) = \frac{\partial}{\partial s_f} \left(\frac{\partial P}{\partial \theta} \right) = \frac{\omega t_p}{\alpha(1 - t_y)(1 - s_r - s_f)^2} \left(\psi + \frac{\omega}{1 - s_r - s_f} \right) < 0 \end{cases} \quad (27)$$

Although an increase in both the monitoring frequency and the subsidy rates reinforces the firm's incentive for environmental protection, the relative effectiveness of marginal changes in the monitoring rate (penalty) and the subsidy rates (rewards) can be measured as

$$\frac{\frac{\theta}{I} \frac{\partial I}{\partial \theta}}{\frac{s_r + s_f}{I} \frac{\partial I}{\partial (s_r + s_f)}} = \frac{1 - s_r - s_f}{s_r + s_f} \left(\frac{\psi}{\omega} (1 - s_r - s_f) + 1 \right) \quad (28)$$

which can be either greater or less than 1. It is noticeable that this policy effectiveness comparison is independent of the firm's production technology and the authorities' policy mix except their subsidies rates. In other words, the stick (monitoring) works more effectively than the carrots (subsidies) at the margin when

$$\frac{\psi}{\omega} > \frac{2(s_r + s_f) - 1}{[1 - (s_r + s_f)]^2} \quad (29)$$

This implies that the authority will more likely to resort to a harsher monitoring scheme for (a) dirty industries (where ψ is big) or (b) firms with inefficient abatement facilities (where ω is small). Denote the maximum profit the firm can achieve by $\Pi^*(K, t_y, t_p, \theta, s_r, s_f)$, we can obtain the following result by using the first order condition

$$\begin{aligned} \frac{\partial \Pi^*}{\partial (s_r + s_f)} &= (1-t_y) \frac{\partial Y}{\partial (s_r + s_f)} - \theta t_p \frac{\partial P}{\partial (s_r + s_f)} \\ &= \theta t_p \left(\psi + \frac{\omega}{1 - s_r - s_f} \right) \frac{I}{1 - s_r - s_f} \\ &= MB(K, t_y, t_p, \theta, s_r, s_f) \frac{\partial C}{\partial I} I > 0 \end{aligned} \quad (30)$$

where MB is the marginal benefit of the investment for pollution control as presented on the right hand side of (12). Therefore, the firm will always have incentive to seek for subsidies whenever it is available if the effective tax rate is not trivial.

The SEPA's Problem

The SEPA behaves on the behalf of the state (regional) authority, which cares its net tax revenue presented as

$$R = t_y Y + \theta t_p P - \theta M + \eta [\theta s_f M - (1 - \theta) F] - s_r C \quad (31)$$

where M is the SEPA's monitoring cost, η is the FEPA's inspection rate, and s_f is the federal subsidy rate to the SEPA's monitoring cost. Pollution concerns are assumed to be secondary to the state authority and affect the SEPA's objective function through the pollution tax, monitoring scheme, and the federal penalty on noncompliance of the environmental law. In practice, the tax rates, subsidy rates are legislated by law makers. The monitoring cost is fixed. The SEPA can only use its monitoring frequency as its decision variable. The tax variation with respect to changes of θ is

$$\frac{dR}{d\theta} = t_y \frac{\partial Y}{\partial \theta} + t_p P + t_p \theta \frac{\partial P}{\partial \theta} - M + \eta (s_f M + F) - s_r \frac{\partial C}{\partial \theta} \quad (32)$$

The second order derivative is

$$\frac{d^2 R}{d\theta^2} = \frac{t_p^2}{2\alpha(1-t_y)} \left(\frac{2-t_y}{1-t_y} \right) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2 < 0 \quad (33)$$

Hence, the second order condition for the SEPA's maximization problem is satisfied for any feasible choice of θ . Therefore, the first order condition for the SEPA's optimal choice of the monitoring rate is

$$MC_r = M - \eta s_F M + s_r \frac{\partial C}{\partial \theta} - t_y \frac{\partial Y}{\partial \theta} - t_p \theta \frac{\partial P}{\partial \theta} = \eta F + t_p P = MB_r \quad (34)$$

Substitutions lead to

$$\begin{aligned} & (1-\eta s_F) M + \frac{s_r t_p}{2\alpha(1-s_r-s_f)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) - \theta \left[\frac{t_y}{2\alpha} \left(\frac{t_p}{1-t_y} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) \right)^2 + \frac{t_p^2}{2\alpha(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) \right] \\ & = \eta F + t_p \left[-\frac{\beta \psi}{2\alpha} - \frac{\omega}{1-s_r-s_f} \left(K + \frac{\beta}{2\alpha} \right) + \frac{\theta t_p}{2\alpha(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2 \right] \end{aligned} \quad (35)$$

The left hand side of (35) is the SEPA's aggregate marginal monitoring cost, consisting of (a) marginal monitoring cost, (b) marginal subsidy cost, (c) marginal cost due to the reduction of the VAT base, and (d) marginal cost due to the reduction of pollution tax base. The right hand side of (35) is the SEPA's marginal monitoring benefit, including some potential penalty avoided and some incremental pollution tax levied due to a harsher monitoring scheme. From the balance of the marginal cost and marginal benefit of the SEPA monitoring, we can express the SEPA's optimal choice as its best reaction function to the FEPA's policy mix and the firm's optimal behavior, namely,

$$\theta = \max \left\{ 0, \min \left\{ 1, \frac{t_p \left[\frac{\beta \psi}{2\alpha} + \frac{\omega}{1-s_r-s_f} \left(K + \frac{\beta}{2\alpha} \right) \right] + M - \eta (s_f M + F) + \frac{s_r t_p \left(\psi + \frac{\omega}{1-s_r-s_f} \right)}{2\alpha (1-s_r-s_f) (1-t_y)}}{\frac{t_p^2 (2-t_y)}{2\alpha (1-t_y)^2} \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} \right\} \right\} \quad (36)$$

For the optimal solution for θ being interior in $[0,1]$, the SEPA has a positive response to the federal subsidization on monitoring, namely,

$$\frac{\partial \theta}{\partial s_f} = - \frac{2\alpha \eta M (1-t_y)^2}{t_p^2 (2-t_y) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} > 0 \quad (37)$$

Meanwhile, the more frequently the FEPA inspects, the more frequently the SEPA monitors. This can be seen from

$$\frac{\partial \theta}{\partial \eta} = - \frac{2\alpha (1-t_y)^2 (s_f M + F)}{t_p^2 (2-t_y) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} > 0 \quad (38)$$

From (37) and (38), we know that subsidies for monitoring and improvement for inspection share the same qualitative impact on the SEPA's behavior. However, the effectiveness elasticities of these two policy instruments are different:

$$\frac{\frac{s_f}{\theta} \frac{\partial \theta}{\partial s_f}}{\frac{\eta}{\theta} \frac{\partial \theta}{\partial \eta}} = \frac{s_f M}{s_f M + F} < 1 \quad (39)$$

which implies that only when the penalty for the SEPA's noncompliance of the environmental law is insignificant, the FEPA would assume that the inspection and the subsidy for SEPA monitoring have almost identical effectiveness at margin. Nevertheless, it is clear that the federal subsidy to SEPA contributes to effectiveness of its inspection scheme,

$$\frac{\partial}{\partial s_F} \left(\frac{\partial \theta}{\partial \eta} \right) = - \frac{2\alpha M(1-t_y)^2}{t_p^2(2-t_y) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} > 0 \quad (40)$$

Other results that were already discussed in the earlier paper include: (i) the higher the penalty level, the more frequently the SEPA monitors, and (ii) the higher the SEPA monitoring cost, the less frequently the SEPA monitors, i.e.,

$$\frac{\partial \theta}{\partial F} = - \frac{2\alpha \eta (1-t_y)^2}{t_p^2(2-t_y) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} > 0 \quad (41)$$

$$\frac{\partial \theta}{\partial M} = \frac{2\alpha (1-t_y)^2 (1-\eta s_F)}{t_p^2(2-t_y) \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2} < 0 \quad (42)$$

For given F and s_F , the minimum required FEPA inspection rate to make the SEPA move is

$$\eta_{\min} = \frac{1}{s_F M + F} \left[\frac{\beta \psi t_p}{2\alpha} + \frac{\omega t_p}{1-s_r-s_f} \left(K + \frac{\beta}{2\alpha} \right) + M + \frac{s_r t_p \left(\psi + \frac{\omega}{1-s_r-s_f} \right)}{2\alpha (1-s_r-s_f) (1-t_y)} \right] \quad (43)$$

The FEPA's Problem

The federal authority is, at large, growth-oriented and thus cares the economy's output the most. However, it has to face the pressure from taxpayers to preserve the environmental quality, and thus has a disutility on pollution. Taking the budgetary constraint into consideration, we can assume that the federal authority's preference is represented by the following social welfare function

$$W(Y, P) = Y - \lambda p(Y, C) + \mu [\eta (1-\theta) F - \theta s_F M - s_f C - \eta m] \quad (44)$$

where m is the FEPA's inspection cost when an inspection is conducted. Here λ is the marginal disutility of pollution and μ is the multiplier of

the FEPA's financial constraint. λ can also be interpreted as the FEPA's marginal substitution rate between the output and pollution,

$$\lambda = \left. \frac{\partial Y}{\partial P} \right|_{W = W_0} \quad (45)$$

In the principal-agent relationship between the FEPA and the SEPA, we can see how the agent's behavior would affect the principal's payoff at any given FEPA inspection rate, namely,

$$\begin{aligned} \frac{\partial W}{\partial \theta} &= \frac{\partial Y}{\partial \theta} - \lambda \frac{\partial P}{\partial \theta} + \mu \left[-\eta F - s_F M - s_f \frac{\partial C}{\partial \theta} \right] \\ &= -\frac{t_p}{2\alpha(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2 \left[\lambda - \frac{\theta t_p}{1-t_y} \right] - \mu \left[\eta F + s_F M - \frac{s_f t_p}{2\alpha(1-s_r-s_f)(1-t_y)} \left(\psi + \frac{\omega}{1-s_r-s_f} \right)^2 \right] \end{aligned} \quad (46)$$

Two important policy messages are implied by this observation. When the SEPA tries to raise its monitoring rate while the FEPA maintains a fixed inspection rate, then (a) the both output level and pollution intensity in the environment will be reduced and the FEPA prefers this output-pollution trade off only when it has a sufficiently high marginal (average) disutility on pollution, hence a federal authority with little awareness on environmental protection may not necessarily welcome a voluntary SEPA monitoring improvement; and (b) financially, the FEPA will suffer from a revenue loss, since marginally it will (i) collect less penalty from the SEPA with improved compliance, (ii) assume a larger subsidy to the SEPA's monitoring, and (iii) fortify its subsidy to the firm due to a bigger firm investment for pollution control caused by a stricter SEPA monitoring behavior.

Recall that the FEPA is the upper-most Stackelberg leader in this multi-level game, it knows that its decision on inspection will directly affect the SEPA's policy making and thus the firm's profit maximization behavior. So, we can rewrite the FEPA's objective function as

$$W(\eta) = Y[\theta(\eta)] - \lambda P[\theta(\eta)] + \mu \{ \eta [1-\theta(\eta)] F - \theta(\eta) s_F M - s_f C[\theta(\eta)] - \eta m \} \quad (47)$$

The first order derivative of the objective function is

$$\frac{dW}{d\eta} = \left(\frac{\partial Y}{\partial \theta} - \lambda \frac{\partial P}{\partial \theta} \right) \frac{\partial \theta}{\partial \eta} + \mu \left[(1-\theta) F - m - \left(\eta F + s_F M + s_f \frac{\partial C}{\partial \theta} \right) \frac{\partial \theta}{\partial \eta} \right] \quad (48)$$

The second order derivative of the objective function is

$$\frac{d^2 W}{d\eta^2} = \frac{\partial^2 Y}{\partial \theta^2} \left(\frac{\partial \theta}{\partial \eta} \right)^2 - 2\mu F \frac{\partial \theta}{\partial \eta} = \frac{1}{2\alpha} \left[\frac{t_p}{1-t_y} \left(\psi + \frac{\omega}{1-s_r-s_f} \right) \right]^2 \left(\frac{\partial \theta}{\partial \eta} \right)^2 - 2\mu F \frac{\partial \theta}{\partial \eta} < 0 \quad (49)$$

Hence the second order condition for the FEPA's maximization problem is satisfied for all feasible choice of η in $[0,1]$. Therefore, the FEPA has a unique optimal choice of its inspection rate, which can be determined from the following equation,

$$MC_F = - \frac{\partial Y}{\partial \theta} \frac{\partial \theta}{\partial \eta} + \mu \left(m + s_f \frac{\partial C}{\partial \theta} \frac{\partial \theta}{\partial \eta} + \eta F \frac{\partial \theta}{\partial \eta} + s_F M \frac{\partial \theta}{\partial \eta} \right) = \mu [1-\theta(\eta)] F - \lambda \frac{\partial P}{\partial \theta} \frac{\partial \theta}{\partial \eta} = MB_F \quad (50)$$

Intuitively, we see that the FEPA shall set its aggregate marginal inspection cost equal its aggregate marginal inspection benefit in terms of pollution intensity reduced and marginal increase of the penalty collected from the SEPA. Here, the FEPA's aggregate marginal inspection cost has five components: (1) the direct marginal inspection cost, (2) the marginal cost due to output reduction caused by a tighter environment quality control, (3) the marginal cost due to the federal subsidy to the firm, (4) the marginal cost due to the federal subsidy the SEPA's monitoring, and (5) the marginal reduction in the penalty collected from the SEPA since a higher inspection rate induces a stronger incentive for SEPA to comply the environmental law. Taking (50) as an implicit function relating policy parameters and the firm's technology and pollution status, we have

$$\frac{\partial \eta}{\partial \lambda} = - \frac{- \frac{\partial P}{\partial \theta} \frac{\partial \theta}{\partial \eta}}{\frac{d^2 W}{d\eta^2}} > 0 \quad (51)$$

which implies that the more the FEPA dislikes the pollution, the more frequently the FEPA will inspect the SEPA. Furthermore,

$$\frac{\partial \eta}{\partial \mu} = - \frac{(1-\theta) F - m - \left(\eta F - s_F M - s_f \frac{\partial C}{\partial \theta} \right) \frac{\partial \theta}{\partial \eta}}{\frac{d^2 W}{d \eta^2}} \quad (52)$$

which implies that whether or not the rise of the FEPA's shadow price for budgetary surplus will increase its inspection frequency or not depends on the ensuing financial result of the FEPA inspection scheme. If the subsidization and penalty are designed to generate a self-sustainable inspection scheme, then the FEPA can actually gain net revenue while reducing the damage to the environment. Otherwise, the FEPA's first best inspection plan will be impeded by its shortage of financial resources.

References

- Baumol, W.J. and W.E. Oates, 1988, *The Theory of Environmental Policy*, Prentice Hall, Englewood Cliffs, N.J.
- Clarke, S.F. 1991, "The Tax Treatment of Expenditures on Antipollution Equipment and Facilities in Selected Foreign Countries", Law Library of Congress, LL91-14.
- Eskeland, G. and E. Jimenez, 1991, "Choosing Policy Instruments for Pollution Control - A Review", World Bank, Working Paper, WPS 624, March
- Estache A. and K. Zheng, 1992, "Managing Pollution Control in Brazil: The Potential Use of Taxes and Fines by Federal and States Governments", The World Bank, Working Paper, WPS 929, June
- Fargeix, A. 1992, "Theory and Practice of Pollution Control Financing", The World Bank, January 17
- Kohn, R.E., 1990, Porter's Combination of Tax and Subsidy for Controlling Pollution, *Journal of Economic System* 20(3): 179-
- Laplante, B., 1990, Producer Surplus and Subsidization of Pollution Control Device: A Non- Monotonic Relationship, *Journal of Industrial Economics* 39(1): 15-
- Opshoor, J.B. and H.B. Vos (1989), Economic Instruments for Environmental Protection, OECD, Paris.
- Yohe, G.W. and P. MacAvoy, 1987, A Tax cum Subsidy Regulatory Alternative for Controlling Pollution, *Economics Letter* 25(2): 177-182

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1047	Côte d'Ivoire: Private Sector Dynamics and Constraints	Enrique Rueda-Sabater Andrew Stone	November 1992	P. Infante 37642
WPS1048	Targets and Indicators in World Bank Population Projects	George Baldwin	November 1992	O. Nadora 31091
WPS1049	Money Demand and Seignorage-Maximizing Inflation	William Easterly Paolo Mauro Klaus Schmidt-Hebbel	November 1992	R. Martin 31448
WPS1050	Marginal Income Tax Rates and Economic Growth in Developing Countries	William Easterly Sergio Rebelo	November 1992	R. Martin 31448
WPS1051	The Legal Framework for Private Sector Activity in the Czech and Slovak Federal Republic	Cheryl W. Gray	November 1992	M. Berg 36969
WPS1052	A Reappraisal of How Oral Rehydration Therapy Affected Mortality in Egypt	Hoda Rashad	November 1992	O. Nadora 31091
WPS1053	Development of the Zimbabwe Family Planning Program	Alex F. Zinanga	December 1992	O. Nadora 31091
WPS1054	Distributional Impact of Cash and In-Kind Social Transfers in Eastern Europe and Russia	Branko Milanovic	December 1992	S. Moussa 39019
WPS1055	Wealth, Weather Risk, and the Composition and Profitability of Agricultural Investments	Mark R. Rosenzweig Hans P. Binswanger	December 1992	C. Banton 34783
WPS1056	Earnings and Education in Latin America: Assessing Priorities for Schooling Investments	George Psacharopoulos Ying Chu Ng	December 1992	L. Longo 39244
WPS1057	Measuring the Incomes of Economies of the Former Soviet Union	Socio-Economic Data Division International Economics Department	December 1992	E. Zamora 33706
WPS1058	The Pricing of Country Funds and Their Role in Capital Mobilization for Emerging Economies	Ishac Diwan Vihang Errunza Lemma W. Senbet	December 1992	R. Vo 31047
WPS1059	Political Economy of Policy Reform in Turkey in the 1980s	Ziya Önis Steven B. Webb	December 1992	S. Gustafson 37856

Policy Research Working Paper Series

Title	Author	Date	Contact for paper
WPS1060 Economies of the Former Soviet Union: An Input-Output Approach to the 1987 National Accounts	Dmitri Steinberg	December 1992	E. Zamora 33706
WPS1061 Dynamic Response to Foreign Transfers and Terms-of-Trade Shocks in Open Economies	Klaus Schmidt-Hebbel Luis Serven	December 1992	A. Maranon 31450
WPS1062 Economic Development, Environmental Regulation, and the International Migration of Toxic Industrial Pollution, 1960-88	Robert E. B. Lucas David Wheeler Hemamala Hettige	December 1992	WDR 31393
WPS1063 Mongolia: Privatization and System Transformation in An Isolated Economy	Cevdet Denizer Alan Gelb	December 1992	A. Oropesa 39075
WPS1064 More Evidence on Income Distribution and Growth	George R. G. Clarke	December 1992	R. Martin 39065
WPS1065 Strengthening Uganda's Policy Environment for Investing in University Development	Thomas Owen Eisemon John Sheehan George Eyoku Franklin Van Buer Delane Welsch Louisa Masutti Nat Colletta Lee Roberts	January 1992	C. Cristobal 33640
WPS1066 Pollution Control in a Decentralized Economy: Which Level of Government Should Subsidize What in Brazil	Antonio Estache Kangbin Zheng	January 1992	A. Estache 81442